GAVIN PUBLISHERS

Journal of Earth and Environmental Sciences

Gold J, et al.J Earth Environ Sci 2017: J102.

DOI: 10.29011/JEES-102. 100002

Research Article

Analysis of Modified Sand Filtration for the Capture and Storage of Grey Water Nutrients

Jake Gold[1*], Nabiul Afrooz[1], Alexandria Boehm[1,2]

[1]Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA

[2]Engineering Research Center (ERC) for Re-inventing the Nation's Urban Water Infrastructure (ReNUWIt), USA

[*]**Corresponding author:** Jake Gold, Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA, Tel: +1 6507232544; E-mail: jgold3@stanford.edu

Citation: Gold J, Afrooz N, Boehm A (2017) Analysis of modified sand filtration for the capture and storage of grey water nutrients. J Earth Environ Sci 2017: J102. DOI: 10.29011/JEES-102. 100002

Received date: 01 March, 2017; **Accepted date:** 07, March, 2017; **Published date:** 24, March, 2017

Abstract

For decades, households and local utilities have recycled grey water with passive-media filtration systems. However, little research has been done assessing the contaminant removal performance of individual media. We ran filtration experiments, analyzing the nutrient sorption capacity of bio char, compost, coir, zeolite, and sand. Because of their alkaline surface conditions, all media types preferentially sorbed positively charged nutrients over negatively charged nutrients and thus, ammonia capture was higher than either nitrate or phosphorous capture. Phosphorus compounds, both inorganic and organic, do not sorb as strongly to any media type. Thus, the residual effluent concentrations of P were significantly higher than the California standards for non-potable reuse [1]. Heterogeneities in the grey water influent and an overloading of phosphorous compounds on available active sites likely contributed to the poor P capture and storage. Overall, no single media was ideal for sorbing a broad spectrum of nutrients. Filters composed of two or more media sorb higher percentages of dissolved nutrients because of their increased activity site diversity.

Introduction

Reclaimed grey water, or household wastewater excluding toilets (black water), reduces the regenerative water stresses placed on local reservoirs (EPA, Water Division Region, 1992). Cities can also reduce treatment costs by treating grey water as a separate entity from sewage. Treated grey water has more beneficial uses due to lower concentrations of pathogens or fecal indicator bacteria, Total Suspended Solids (TSS) and Biological Oxygen Demand (BOD). (EPA, Water Division Region, 1992) [2]. There are currently no systems in place for separating grey water from sewage once the effluents leave households [3]. Home owners must treat and redistribute their own grey water on-site by re circulating or repurposing.

Gehring describes four methods of household grey water treatment popular as of 2011. All five treatment options are sustainable, passive strategies incorporating either inorganic or organic media. In most cases, soil and ground laden sediments act as the filtration bed. A low grey water flow velocity results in media sorption and or microbial communities up taking contaminants to drive metabolic pathways [4]. A lowered flow rate occurs in tanks with large hydraulic residence times, or in media beds that greatly increase the available infiltration area.

Aerobic pre treatment relies on a anaerobic tank to reduce organic molecules and capture larger suspended solids by settling. After aerobic treatment, pretreated grey water seeps into the surrounding soil environment and is filtered by sediments and degraded by microorganisms [4]. Homeowners can also An Aerobically Treat grey water before soil filtration Three chamber septic systems capture grease, sludge, and other suspended particles based on size and density. However, users must monitor and maintain the system to remove captured solids and prevent the occurrence of foul odors that accumulate due to anaerobic respiring of noxious compounds [5]. Often, a homeowner will need to add an additional sand filter after the septic system to oxidize anaerobic byproducts into non-volatile species.

Since 1975, people have used the relatively simple and cheap plant soil box with layered mulch and topsoil to passively treat grey water. Grey water percolates through the bio filter and is treated by both sediments grains and micro organisms. The process becomes self-sustaining when grey water nutrient loading equals the metabolic uptake rate in the bio film.

Lastly, Gravity Fed Infiltration within a leaching chamber is an outdoor form of treatment. Grey water seeps through an isolated soil environment and is processed by interactions with soil particles and microbes much to the same extent as the soil box. Switches or pressure activated bottoms release effluent out of the chamber to reflush the media when the chamber becomes saturated.

Each of these described treatment strategies depends on media, in these cases soil. However, soil is a site specific, heterogeneous mixture that may or may not capture certain contaminants [6]. We are interested in improving passive filtration by testing the degree to which individual media s or b nutrients, and categorizing them into an accessible sorption hierarchy to be used when designing new filtration beds. However, dozens of media are sold commercially and or still being tested that may serve as more effective filter. The aim of this experiment is to test a comparable variety of media, ranging from commercial grade to experimental and rank the nutrient sorption properties of each.

Materials and Methods

Media

The five most referenced media in the literature are zeolite, compost, coconut coir, bio char, and sand to function as a control filter. We describe these media in the following section of paper. Zeolite is a naturally occurring, hydrated aluminosilicate that has been used as a filtration media since the mid 70s. For our experiment, we used dehydrated zeolite granules with a mesh size <30. Zeolite has been recognized as a high-performance media and functions as a standard to gauge the sorption capacity of the organic media: coir, bio char, and compost [7].

Compost is a carbon, nitrogen, and phosphorous rich mixture used in agriculture to capture and redistribute nutrient loads. Compost surfaces are abundant with active sites and thus make it a strong candidate for the capture and storage of harmful compounds [8]. Previous research however, has shown that without a steady influx of nutrients, bio available active sites decrease sharply. In addition, compost itself has a large leaching tendency that may counter balance its storage of nutrients over time [9].

Coir is a fibrous material harvested from the outer layer of coconut shells. The material is carbon rich, low in nutrients, and can absorb a significant amount of water [10]. Research conducted at the National University of Singapore found coir sorbed heavy metals significantly worse than compost and soil amendments. Coir leached significant concentrations of humic substances that resulted in sorbed metal ions redis solving back into solution. As of now, little research has been conducted to test coir's ability to sorb nutrients. We bought dehydrated coir bricks and pulverized them into threads and grains before mixing with sand.

Lastly, biochar is a low density, highly porous charcoal made from the pyrolysis of organic matter [11]. Biochar has been the foci for many filtration experiments because of its low emission of formation, and abundance of reactive sites [12]. However, biochar reactivity is largely dependent on the organic matter pyrolized and thus, its sorption potential may vary geographically [13].

Each filtration column was composed of specific media types, as well as bulk sand by volume to prevent buoyant particles such as biochar from floating to the surface [14].

Grey water Recipe

We modified Christina Berger's grey water recipe with higher concentrations of toothpaste and nutrient broth to achieve nutrient levels cited by the 2016, Committee on the Beneficial Use of Grey water and Storm water (Biochar and activated carbon filters for grey water treatment - comparison of organic matter and nutrients removal, 2012). The grey water nutrient concentrations ranged between 1.6-2.0 mg/l ammonia, 0.7-2.1 mg/l nitrate, and 7-23 mg/l phosphate.

A three-liter stock solution was made by mixing

- 0.48g Ariel Detergent
- 0.48g Dish Soap
- 0.48 g shampoo
- 1.2 g corn oil
- 21 g of toothpaste
- 150 ml of nutrient broth
- 280 ml of water

The mixutre was kept on a magneticstir barto prevent susended particles from settling.

Experimental Setup

The filtration experiment lasted two days for each individual column. We pumped DI water and grey water influent erratically through the filters instead of gravity-fed to reduce short circuiting. Short circuiting occurs as gravity-fed filtration takes the path of least resistance through a porous material and avoids pore spaces. This may result in skewed sorption results depending on the packing and porosity of media.

We weighed columns before the leaching test and two hours later to measure the respective pore volumes (pvs). Rather than flush all filters over the same periods of time, we flushed columns based on pore volumes of influent. Regardless of porosity, all exposed media surfaces were in contact with equal volumes of influent.

Grey water Test

After flushing the columns with DI water, we pumped grey water through the filters at a rate of 1.0-milligram per minute. Immediately before filtration, we added bacteria to the influent mixture in similar concentrations to those documented by the Committee on the Beneficial Use of Grey water and Storm water. For reference, when left untreated, grey water bacteria counts increase rapidly within the first 24 hours [15]. We assumed all grey water discharge flowed directly to a filtration unit after its formation.

The solution was left stirring for the duration of the experiment to prevent sedimentation of bacteria and other suspended materials. A previous media filtration study indicated that solute breakthrough occurs after 2 pvs [16]. We collected effluent samples from pv 3-4, 5-6, and 7-8. All samples were immediately frozen at-15°C to prevent changes in nutrient concentration via ammonification and bacterial metabolism.

Statistics

After the samples thawed, we measured nutrient concentrations in both the influent and effluent samples. We used a discrete analyzer to measure inorganic and organic, nitrogen and phosphorus, and then calculated the percent sorption of nutrients over time for each column. We ran an ANOVA on the data to isolate significant sorption trends across media.

Results

Percent Sorption

All five media types sorbed more than 50% of dissolved ammonia (Figure 1). Overall, zeolite captured and stored significantly more ammonia than the other media. Zeolite biochar mixtures sorbed 95% of dissolved ammonia, while five percent zeolite filters sorbed 83-87% of dissolved ammonia. The removal rates within zeolite filters did not fluctuate over successive pvs. In contrast, we observed reduced removal rates in biochar, coir, and compost as pvs increased. Excluding zeolite, the remaining media mixtures captured on average 60-70% of dissolved ammonia.

Nitrate sorption, though consistently positive, was less than ammonia sorption (Figure 1).

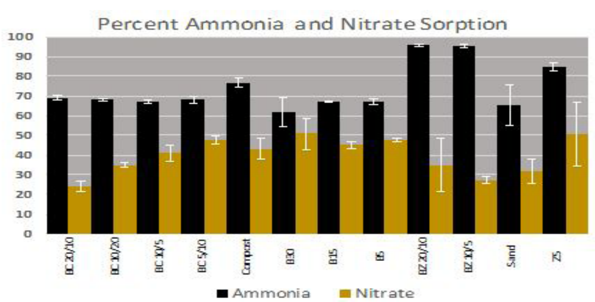

Figure 1: Depicts the average percent removal of both ammonia and nitrate for each filter used in the Experiment. Each value is the average removal during pvs 3-8 for grey water filtration. Acronyms can be elaborated in figure 1 for reference. Ammonia sorption is highest in Zeolite filters and all media preference ammonia over nitrate.

There were no significant differences in nitrate removal rates between media types, except for the control columns. Sand removed less than 30% dissolved nitrate whereas other media ranged between 30% and 60% capture. Filter nitrate capture varied depending on the volume of media used.. Higher volumes of biochar significantly reduced the removal rates within the biochar coir mixtures, and may have reduced the removal rates of the biochar zeolite mixtures as well. However, the biochar sand filters captured more nutrients on average as biochar increased.

Phosphate sorption was more predictable compared to ammonia and nitrate sorption (Figure 2). Filters fluctuated wildly between positive and negative capture of suspended phosphate, even across individual pvs.

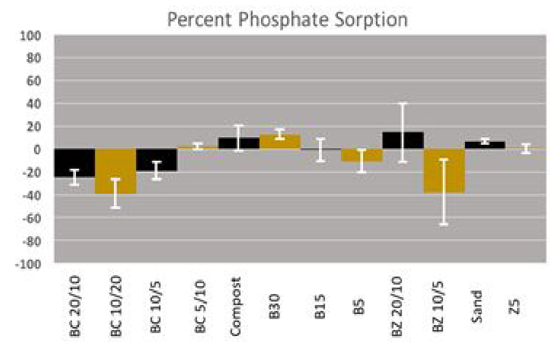

Figure 2: Depicts the average percent of phosphate removed by each filter. Each value is the average removal during pvs 3-8 for grey water filtration. We did not observe any consistent sorption pattern across the media types, but overall phosphate capture was significantly lower than ammonia or nitrate capture.

Discussion

Media Mixtures by percent volume	
(BZ 20/20) 20% biochar / 10% zeolite	(BCC 20/10) 20% biochar / 10% coconut coir
(BZ 10/5 10% biochar / 5% zeolite	(BCC 10/20) 10% biochar / 20% coconut coir
(Z5) 5% zeolite	(BCC 10/5) 10% biochar / 5% coconut coir
(B30) 30% biochar	(BCC 5/10) 5% biochar / 10% coconut coir
(B15) 15% biochar	30% compost
(B5) 55 biochar	100% sand (control)

Table1: List of the 12 filter media combinations tested in this experiment. Percent volumes are indicated to the left of the media used: remaining volume is sand.

Overall Nutrient Sorption

The filtration experiment showed how media sorption is largely charge dependent. The media possess an overall negative surface charge (Revisit media descriptions in the introduction) leading to the preferential sorption of positive ammonia molecules compared to negative nitrates and phosphates. Net surface charges are correlated with the pH of the dissolved solution. Negative charges ad here protons more readily than positive charges and result in the formation of alkaline solutions. However, we would like to mention that the net surface charges of organic substances such as compost and coir are site specific. The compost and coir used in our experiment ranged from pH 7.2-7.7 while other papers site pH values ranging from 5.5 to 8.0 for compost and 6.0-8.0 for coir.

Phosphate Discrepancy

We do not fully understand the higher preference for nitrates compared to phosphates. However, two major factors likely contributed to the low nitrogen and high phosphorus effluent concentrations. Phosphate concentrations in the grey water were one order of magnitude larger than nitrate, and thus, the media may have Quickly addition, studies by Wu and found higher pH values favor the precipitation of phosphates into solution, and media. We also noticed heterogeneities in our synthesized grey water. The toothpaste appeared to coagulate into suspended particles. Since toothpaste is rich in orthophosphates, the presence of these particles in the filters may have caused spikes in our data: leading to high sorption in some media and high leaching in others. For reference, Saitana University (2008), University of Florida (2011), University of Stellenbosch (2007), and the Institute of Agricultural and Nutritional Science (2013) found that coir, biochar, zeolite, and compost respectively sorb phosphate to some extent.

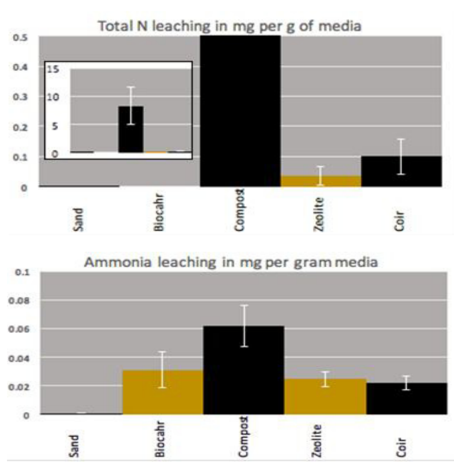

Figure 3 A/B: Figure 3A shows the total organic and inorganic nitrogen leached from each media in mg per gram. The smaller graph is an expanded view of 2B to indicate the magnitude of compost leaching compared to other media. Figure 4B shows the ammonia leached by each media in mg per gram

Individual Nutrient Sorption:

Compost was the least effective filtration media observed. Though it sorbed nutrients to the same degree as coir and biochar, the rich organic composition results in high concentrations of leached inorganic and organic nitrogen and phosphorous [16]. Concentrations of nitrogen, phosphorous, and carbon in the compost effluent were orders of magnitude larger than both other filters and the grey water itself. The N: C ratio in compost is extremely high compared to other organic substances. A higher N: C ratio resulted in the dissolution of nitrogenous compounds: particularly ammonia and organic nitrogen [17]. Upon further research, we found compost was extremely rich in dissolvable orthophosphates [16]. Exposed phosphate groups would have dissolved into solution and added excess P to the effluent. The capture rates observed in compost did not compensate for the leaching levels which often superseded the influent concentrations found in grey water.We observed a similar leaching trend with coir, but still significantly lower than compost. Coir was the most buoyant media tested with a density of approximate 0.30 g/ml.

Media Type	Density: g/ml
Sand	1.8
Zeolite	0.8
Biochar	0.38
Coir	0.3
Compost	0.5-0.7

Table 2: A table measured densities of each media type. Compost has a more fluid density depending on the degree to which compaction occurs.

Thus, by percent volume, coir did not leach significant quantities of nutrients and could be used as an effective media to sorb ammonia from grey water. We are not sure why the presence of biochar reduced the nitrate sorption capacity of the coir filters, particularly because biochar filters removed more nitrate on average than the coir filters. Further filtration tests should reveal whether coir could remove nitrate effectively from grey water without the presence of biochar. Coir could be a cheap and lightweight ammonia filter. However, exclusively using coir as a filter without buffering by sand or another media would cause leaching problems or even media washout.

After initial pvs, biochar leached negligible nutrients and was an effective nutrient sorber. The initial pv spikes in nutrients coincide with finer biochar particles flushing out of the filters as effluent. These particles would have likely sorbed nutrients in the surrounding wastewater and increased effluent concentrations. After the initial filtration, only large biochar grains would have remained in the columns [18].

Previous research has shown that both the high porosity of biochar, and number of active sites allow it to sorb microbes, metals, and nutrients effectively [19]. Like compost, the high organic compositions suggest an abundance of active sites. But since the active sites [20] are not as abundant as zeolite, biochar removal rates decrease more readily with successive pore volumes.

Zeolite has been a commercially used filter media for almost fifty years. The charged surface and abundance of active sites allowed it to sorb high concentrations of nitrate and ammonia. Unlike biochar, zeolite actively sorbed nutrients without a decrease in removal capacity over 8 pore volumes. A study conducted by analyzed the ammonia and nitrate capture of zeolite. Like our results, he found that zeolite sorbed much higher concentrations of ammonia than nitrate. The negative surface charge forms because of the presence of CaCO3 and MgCO3.Both carbonates hydrolyze in solution, creating a strong negative surface charge as the metal cations dissolve in solution.

Sand and zeolite were the only two inorganic media and therefore possessed fewer nitrogen, carbon, and phosphorous groups on their surfaces. In biochar, coir, and compost, these groups easily dissolved in solution, and led to the nutrient spikes seen during the beginning pvs of filtration. The organic media should be cleaned prior to use in filter beds to prevent dissolvable nutrient runoff. Generally, the level of leaching correlated with the coloration of the effluent. The transition from murky effluent to clear can be a visual cue for a reduction in dissolved nutrients. Compost, having a much higher C, N, and P composition continuously leached brown effluent through all observed pvs. Whereas and zeolite produced clear effluent.

Conclusion

A mixture of biochar and zeolite granules is most effective at removing nitrogenous compounds from grey water. Phosphate sorption remains unpredictable across media types, but appears to be weak on average. Further research is required to reduce heterogeneities in our synthesized grey water, and identify more successful phosphate sorbers. Likely, a metallic component will need to be mixed with an organic media to better capture and retain a broad range of nutrients. Diverse filter types preference and adhere a larger range of dissolved contaminants. The benefit of sorbing one class of compounds can be counteracted by leaching of another as shown with compost. Individual media studies will continue to enhance our understanding of a contaminant removal, and lead to higher quality, more sustainable filtration methods in the future.

References

1. Ballantine Jade (2005) Code of Practice for vessel and facility management (marine and inland waters), Environment Protection Authority.
2. Elisa H (2012) Gray Is the New Green. EPA.
3. Anand Sandhya (2016) Waste Water Treatment Steps: Primary, Secondary and Tertiary Treatment." Waste Water Treatment Steps: Primary, Secondary and Tertiary Treatment. Biotecharticles 12.
4. Chang N, Marty W, Ammarin D, Fahim H, Zhemin X, et al. (2010) Onsite Sewage Treatment and Disposal Systems: Evaluation for Nutrient Removal 2010: 1-85.
5. Benami M, Osnat G, Amit G (2016) Potential Health and Environmental Risks Associated with Onsite Greywater Reuse: A Review. Built Environment 42: 212-229.
6. Tufenkji N, Miller GF, Ryan JN, Harvey RW, Elimelech M (2004) Transport of Cryptosporidium Oocysts in Porous Media: Role of Straining and Physicochemical Filtration. Environ Sci Technol 38: 5932-5938.
7. Wu D, Zhang B, Li C, Zhang Z, Kong H (2006) Simultaneous Removal of Ammonium and Phosphate by Zeolite Synthesized from Fly Ash as Influenced by Salt Treatment."Journal of Colloid and Interface Science 304: 300-306.
8. Sommer SG (2001) Effect of Composting on Nutrient Loss and Nitrogen Availability of Cattle Deep Litter."European Journal of Agronomy 14: 123-133.
9. Lim HS, Lim W, Hu JY, Ziegler A, Ong SL (2015) Comparison of Filter Media Materials for Heavy Metal Removal from Urban Stormwater Runoff Using Biofiltration Systems. J Environ Manage 147: 24-33.
10. Mukherjee, Nikkilesh. (2014) Gravity Filters: Why Air Locking Is an Issue?
11. Norio T, Karunarathna AK, Jindasa KBSN (2008) Effect of Coconut Coir-pith Supplement on Nitrogen and Phosphate Removal in Subsurface Flow Wetland Microcosms. Chemistry and Ecology 24: 15-22.
12. Gurwick NP, Moore LA, Kelly C, Elias P (2013) A Systematic Review of Biochar Research, with a Focus on Its Stability in Situ and Its Promise as a Climate Mitigation Strategy. PLoS One 8: e75932.
13. Foereid B (2215) Biochar in Nutrient Recycling—The Effect and Its Use in Wastewater Treatment."OJSS Open Journal of Soil Science 5: 39-44.
14. Committee on the Beneficial Use of Gray water and Storm water (2016) Using Graywater and Stormwater to Enhance Local Water Supplies. An Assessment of Risks, Costs, and Benefits.
15. Palmer ET, Poor CJ, Hinman C, Stark JD (2013) Nitrate and Phosphate Removal through Enhanced Bioretention Media: Mesocosm Study. Water Environ Res 85: 823-832.
16. Morgenroth E, Schroeder ED, Chang DP, Scow KM (1996) Nutrient Limitation in a Compost Biofilter Degrading Hexane."Journal of Air and Wastewater Management 46 : 300-308.
17. Beesley L, Moreno-Jiménez E, Gomez-Eyles JL, Harris E, Robinson B, et al. (2011) A Review of Biochars' Potential Role in the Remediation, Revegetation and Restoration of Contaminated Soils. Environ Pollut 159: 3269-3282.
18. Yao Y, Gao B, Inyang M, Zimmerman AR, Cao X, et al. (2011) Biochar Derived from Anaerobically Digested Sugar Beet Tailings: Characterization and Phosphate Removal Potential. Bioresour Technol 102: 6273-6278.

19. Tian J, Susan Y, Paul TI, Pei C (2014) Mingxin Guo, Julia A. Maresca, Valentina Beneski, and Samuel H. Cooksey. Biochar-Amended Media for Enhanced Nutrient Removal in Stormwater Facilities. World Environmental and Water Resources Congress.

20. Mazeikiene A, Marina V, Mindaugas R, Algirdas BM, Regimantas D (2007) Removal of Nitrates and Ammonium Ions from Water Using Natural Sorbent Zeolite (clinoptilolite). J of Env Eng & Landscape Man 16: 38-44.